

THE ROLE OF BLOCKCHAIN IN ENHANCING TRUST: A CONSTRUCTION PROJECT GOVERNANCE APPROACH

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Abstract

Construction project governance (CPG) offers a strategic framework to guide participants through complex construction projects. Emphasizing the trust mechanism within CPG is crucial for managing inter-organizational relationships. Blockchain (BC) can serve as an enabler for trust-based CPG by facilitating and regulating relationships at the project level. Accordingly, this paper aims to identify CPG's trust requirements and assess the relationship between CPG's trust requirements and BC's characteristics through a state-of-the-art review. The results indicate that integrating BC's distinctive characteristics across project delivery can enhance CPG's trust requirements. This study presents comprehensive guidelines for developing a trust-based CPG model.

Introduction

Construction projects face temporal constraints, including limited duration, unique tasks, ambiguous hierarchies, diversity, and ad-hoc coordination (Sergeeva, 2019). These temporal aspects negatively impact long-term engagement, crucial for establishing trust among project stakeholders (Yan and Zhang, 2020). Trust describes relational aspects such as shared confidence and positive expectations that each organization will act in a mutually beneficial way (Li *et al.*, 2021). Trust between project stakeholders is one of the most critical factors for successful construction projects (Qian and Papadonikolaki, 2020). To establish trust, a comprehensive construction contract should clearly outline the requirements, obligations, and specifications of all project stakeholders. However, incomplete contracts arise during construction projects due to project stakeholders' bounded rationality and asymmetric information (Winch, 2010). As a result, continuous adjustment between project stakeholders is necessary throughout the project life cycle (Mansor and Rashid, 2016). As such, incomplete formal contracts with transactional relationships and informal agreements governing complex construction projects failed to ensure high trust at the project level, leading to issues like time delays, cost overruns, and compromised project quality (Liu *et al.*, 2022).

Construction project governance (CPG) offers new insights into the trust challenge from a broader perspective (Lin *et al.*, 2020). It aims to guide construction projects toward meeting stakeholders'

goals by inducing collective behaviors through efficient regulation and principles (Müller and Martinsuo, 2015). Providing structures, processes, decision-making frameworks, and project management tools, CPG aligns objectives with each stakeholder's organizational governance models (PMI, 2017). However, the current CPG's rigid monitoring, strict contractual management, and rigorous audit mechanisms decrease communication, transparency, cooperation, and motivation, leading to low trust in construction projects (Lin *et al.*, 2020).

Blockchain (BC) has the potential to establish a trust-based CPG (Xu *et al.*, 2022). BC can facilitate the trust mechanism of CPG by directing network participants' behaviors through autonomous services and effectively governing relationships among BC network participants by enabling reliable information sharing (Lumineau *et al.*, 2021). As a digital ledger technology, BC chronologically records transactions across a peer-to-peer network (Das *et al.*, 2020). It provides real-time transmission for synchronized and immutable data through predetermined consensus algorithms, securing block-linked databases via cryptography and hashing algorithms (Perera *et al.*, 2020). However, existing research has not revealed the relationship between CPG's trust requirements and BC (Xu *et al.*, 2022). Therefore, this research aims to explore the trust requirements of CPG and assess the relationship between these requirements and BC characteristics through a state-of-the-art review.

Research Methodology

This study employed a state-of-the-art literature review to provide insights into current scientific advancements (Barry *et al.*, 2022) and fresh viewpoints on the association between BC characteristics and trust requirements in CPG.

Table 1: Database, inclusion criteria, and search terms for a state-of-the-art review

Category	Details
Database	Scopus and Web of Science
Inclusion criteria	Academic journal papers
Search terms	("trust" OR "governance" OR "relational governance" OR "relational norm" OR "construction") AND "blockchain"

The Scopus and Web of Science academic databases were used to source high-quality scholarly articles. Details regarding inclusion criteria and specific search terms are outlined in Table 1.

Figure 1 outlines the methodology of the comprehensive review carried out in this study.

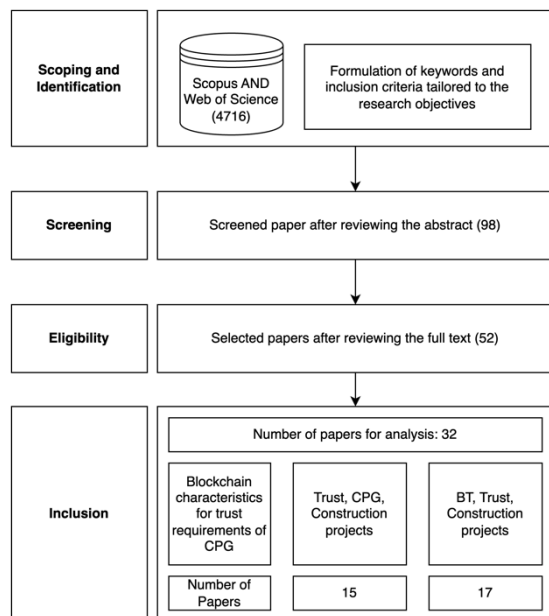


Figure 1: The state-of-the-art review process (devised by authors)

Specifically, the initial step involved a preliminary examination and identification of pertinent literature using specific keywords and inclusion criteria within the chosen database. The second step entailed a screening phase conducted through an abstract analysis. The final selection of 32 papers for in-depth analysis was made after an eligibility assessment based on a full-text review. Hence, the thorough review identified a gap in the existing literature, particularly its lack of exploration into the connection between BC characteristics and trust requirements of CPG.

Trust in Construction Project Governance

A common-pool resource is a shared resource that can be used without causing any harm under favorable conditions (Ostrom, 2019). A construction project can be regarded as a common resource scenario with a shared resource pool, decision-making rights, and risk/reward. Common-pool resource scenarios governed by a top-down governance approach exhibit multiple systematic failures (Hall and Bonanomi, 2021). However, the current CPG is biased towards top-down project governance using contractual project governance rather than bottom-up project governance. This top-down governance approach using rigorous monitoring processes and strict contract terms and conditions decreases trust at the project level (Sergeeva, 2019).

Additionally, according to agency theory and transaction cost economics, construction project stakeholders can be opportunistic, selfish, and possess bounded rationality in the common-pool resource contexts (Winch, 2010; Hall and Bonanomi, 2021). Trust is critical to limit these negative features of legally intertwined entities by facilitating mutual benefits, knowledge sharing, and emotional bonds (Laan *et al.*, 2012). As such, trust can improve project performance by achieving unique objectives within a set period and controlling uncertainty and fragmentation in complicated construction processes (Lu *et al.*, 2021b). In particular, trust is essential when uncertain situations and issues bearing risk occur. It can lead to a reliable relationship based on practical cooperation (Lakusic, 2021). However, fragmented construction processes, the temporality of projects, and project stakeholders' opportunistic behaviors hinder the establishment of trust in the construction project environments (Ke *et al.*, 2015).

Furthermore, self-organization explains the phenomenon where many agents interact with each other in a disordered complex situation but increase order and regularity through the interaction between spontaneous agents. Due to the uncertainties of the construction contract system, the agents participating in the construction project voluntarily form a self-organizing network to address these uncertainties (Steen *et al.*, 2018). Specifically, stigmergy is an example of self-organization involving indirect communication and learning processes through non-linear rules and methods. This provides a basis for understanding social agent interaction that induces complex patterns (Ramos and Abraham, 2004). Stigmergic principles need more flexible project governance structures and play an important role in building trust in construction projects by providing reliable coordination solutions and inducing collective actions within limited information-sharing environments (e.g., construction projects) (Dounas *et al.*, 2022).

Trust Requirements of Construction Project Governance

While agency theory and transaction cost economics as project governance theories provide the contexts of low trust in construction projects involving multiple project stakeholders, contingency and network theories provide the foundation for conceptualizing and understanding CPG's three trust requirements (mutuality, flexibility, and solidarity) derived from relational norms (Lu *et al.*, 2015; Musawir *et al.*, 2020):

- **Mutuality:** Willingness to mutually improve the current situation compared to the previous situation.

- Flexibility: Willingness to accept adjustments and modifications according to changed circumstances.
- Solidarity: Willingness to maintain and stabilize partner relationships.

Table 2 collates trust requirements underpinned by contingency and network theories, from the 15 reviewed papers on Trust CPG, Construction projects.

Table 2: Research on trust requirements of CPG contexts

Authors	Trust requirements		
	Mutuality	Flexibility	Solidarity
(Tian <i>et al.</i> , 2023)		✓	✓
(Paswan <i>et al.</i> , 2017)	✓		✓
(Liu <i>et al.</i> , 2022)		✓	✓
(Benítez-Ávila <i>et al.</i> , 2019)		✓	✓
(Zheng <i>et al.</i> , 2008)		✓	✓
(Chakkol <i>et al.</i> , 2018)		✓	
(Xu <i>et al.</i> , 2022)	✓	✓	✓
(Lu <i>et al.</i> , 2015)	✓	✓	✓
(Yang <i>et al.</i> , 2022)	✓	✓	✓
(Lin <i>et al.</i> , 2020)	✓		
(Haq <i>et al.</i> , 2019)		✓	✓
(Müller and Martinsuo, 2015)		✓	✓
(Benítez-Ávila <i>et al.</i> , 2018)		✓	✓
(Bonatto <i>et al.</i> , 2020)		✓	✓
(Cao and Lumineau, 2015)		✓	✓

Contingency theory focuses on organizational effectiveness, described as the degree of alignment between the organizational characteristics and contingencies reflecting an organization's internal and external environment (Lizarralde *et al.*, 2011). Contingency theory posits that contingency variables (such as governance, size, culture, strategies, stakeholder motivations, or legal frames) align with the changing internal and external environment to improve organizational performance (such as time, cost, quality, scope, and benefit) and thus facilitate mutuality and solidarity (Deng and Smyth, 2013). The dynamic and flexible nature of contingency theory through its continual response to changing environments, suits the examination

of various types of construction projects from diverse and complex backgrounds (Hanisch and Wald, 2012). However, construction project's temporality including limited duration, featuring ambiguous hierarchies, diversity, and informal coordination hinders the establishment of trust at the project level (Deng and Smyth, 2013). According to the contingency, CPG should highlight three relational norms: mutuality, flexibility, and solidarity among construction project stakeholders. These relational norms enhance trust by increasing responsiveness to the internal and external environments at the project level (Musawir *et al.*, 2020; Xu *et al.*, 2022). In addition to contingency theory, network theory emphasizes the efficiency of a network comprising multiple stakeholders participating in a construction project (Wang and Yin, 2023). Like the contingency theory, the network theory emphasizes flexibility, solidarity, and mutuality of relational norms as trust requirements through networking and a network's efficiency (Musawir *et al.*, 2020). Network theory is a subset of graph theory, which is the study of the properties of graphs and the mathematical definition of networks. In general terms, a graph is composed of nodes (objects that constitute the graph) and edges, representing the relationship between the nodes. Graph theory is used to analyze connected node data through various graph algorithms, such as basic statistics, graph data queries, visual exploration, and machine learning (Needham and Hodler, 2019). Similarly, network theory focuses on research into the connection patterns, network structures, node positions, and node outcomes of actors corresponding to the nodes in the graph. Accordingly, network theory is used in social science to study the characteristics of human society, such as group phenomena and human communications (Lu *et al.*, 2015b). Hence, network theory is widely used in project governance, requiring network thinking to study complex construction project networks (Li *et al.*, 2020). However, the non-linear execution of the construction project network, self-organization of multiple stakeholders within that network, and various emergent project situations can decrease network efficiency.

In response to these trust requirements, BC has been focused on as a potential solution to meet CPG's trust requirements (Lumineau *et al.*, 2021; Xu *et al.*, 2022).

Fundamentals of Blockchain Technology

BC consists of four fundamental technologies (Nawari and Ravindran, 2019; Perera *et al.*, 2020):

- P2P networks enable nodes to efficiently store, share, and manage files in a decentralized manner, enhancing speed and security in various digital services without requiring a central server.
- Hashing algorithms assure consistent outputs for identical inputs and resistance to reverse calculation, linking multiple transactions within a BC.

- Cryptography secures data in BC networks, employing either symmetric methods (fast but less secure) or asymmetric methods (more secure but computationally intensive).
- Consensus algorithms aim to maintain transaction orders even in adversarial environments by ensuring agreement among nodes on a single piece of data. These algorithms prevent malicious actions, addressing the Byzantine Generals' Problem, describing how Byzantine troops attacked a completely enclosed city.

Characteristics of Blockchain Technology in Construction Project Governance Contexts

A permissioned blockchain, known as a consortium blockchain, is appropriate for governance contexts in construction projects (Zhong *et al.*, 2020). A synthesis of literature from the 17 reviewed papers on BC, trust and CPG revealed the fundamentals of BC lead to six significant BC characteristics (see Table 3) in the permissioned BC contexts:

Table 3: The characteristics of blockchain in the construction project governance contexts

Characteristics	Details
Autonomy	Blockchain offers a range of autonomous services using smart contracts, which function as computerized protocols for business logics (Nawari and Ravindran, 2019).
Decentralization	Blockchain, as a digital ledger system, operates without a central administrator and a centralized data storage framework (Perera <i>et al.</i> , 2020).
Immutability	Once data are added in the blockchain networks, transactions on the blockchain cannot be canceled or altered (Das <i>et al.</i> , 2020).
Security	Blockchain protects data and prevents fraud by using public keys for network transactions and private keys for managing confidential information (Ciotta <i>et al.</i> , 2021).
Traceability	Every transaction on the blockchain is accurately recorded and timestamped, allowing network participants to access and track these records on any node (Msawil <i>et al.</i> , 2022).
Transparency	Authorized participants in the blockchain networks or channels have access to the same version of data (Teisserenc and Sepasgozar, 2021).

The Relationship Between Trust Requirements of Construction Project Governance and Characteristics of Blockchain Technology

There are strong relationships between CPG trust requirements and BC characteristics in construction project contexts characterized by a common pool resource and stigmergy (see Figure 2).

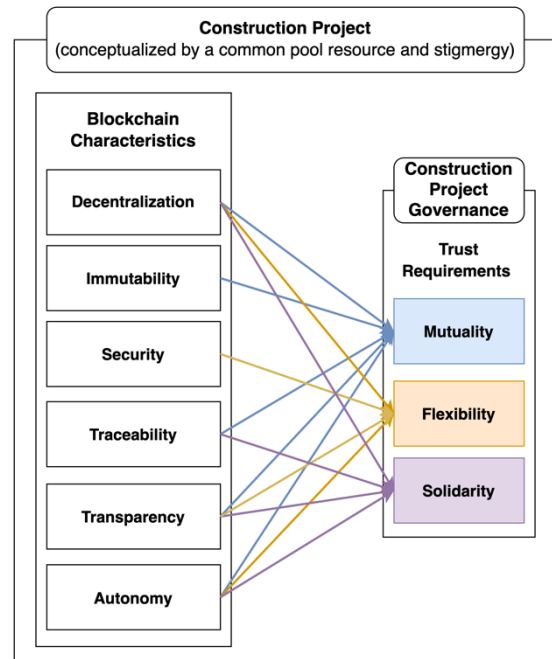


Figure 2: Blockchain characteristics and trust requirements of construction project governance (devised by authors)

First, decentralization, transparency, traceability, immutability, and autonomy are key factors that can enhance mutual relationships among project stakeholders. Decentralization can promote mutuality by creating interconnected networks that are directly operated by distributed entities without any central authority at the project level (Ciotta *et al.*, 2021). Transparency and traceability allow authorized project stakeholders to verify the actions of other network participants, thus promoting mutual trust (Das *et al.*, 2022). Immutability is also vital in mutual relationships, as it ensures that data is not altered or tampered with (Lu *et al.*, 2021b). Autonomy can positively impact mutuality by enabling transparent obligations and increasing the commitment of network participants through smart contracts with coded terms (Xu *et al.*, 2022). These transparent obligations and increased commitments align with the principle of mutuality (Nawari and Ravindran, 2019). Thus, blockchain technology can help establish mutual relationships that are based on a willingness to improve the current situation at the project level (Perera *et al.*, 2020). Second, decentralization, transparency, security, and autonomy can significantly improve flexibility in the context of CPG (Ciotta *et al.*, 2021). Compared to centralized systems, BC's decentralized architecture enhances flexibility in

terms of response time against the risk of system failures or attacks (Fiorentino and Bartolucci, 2021). On the other hand, transparency and security enable reliable and secure information sharing, which positively impacts behavioral flexibility by allowing project stakeholders to respond quickly and efficiently to internal and external changes (Wang and Yang, 2022). Likewise, autonomy increases flexibility for data integration into a secure network by governing data access control within the construction project network (Msawil *et al.*, 2022). As a result, blockchain-enabled flexibility can help construction project stakeholders adapt effectively to any adjustments against rapidly changing external environments (Perera *et al.*, 2020).

Finally, decentralization, transparency, traceability, and autonomy are important factors that contribute to solidarity among stakeholders in construction projects (Xu *et al.*, 2022). Decentralization and autonomy enable the democratization of control in the CPG context, which promotes equal and participatory decision-making processes (Das *et al.*, 2022). This, in turn, leads to better solidarity through collaboration among project stakeholders (Perera *et al.*, 2020). For example, decentralized autonomous organizations and voting applications through BC ensure that stakeholders work together through a fair democratic system for collective decision-making (Nawari and Ravindran, 2019). Transparency and traceability are essential for promoting ethical practices and establishing an accountable cultural system in construction projects. This positive culture promotes solidarity from the project stakeholders at the project level (Li *et al.*, 2019). As a result, the strengthened solidarity positively impacts stakeholders' willingness to maintain and stabilize relationships (Yang *et al.*, 2022).

Hence, focusing on CPG trust requirements (mutuality, flexibility, and solidarity) through BC enables flexible bottom-up rather than top-down governance, enhancing trust at the project level (Xu *et al.*, 2022). Accordingly, the network-based bottom-up project governance through BC aligns with the stigmergy of construction projects as a common pool resource (Dounas *et al.*, 2022; Hall and Bonanomi, 2021).

Discussion

The first objective of this study was to explore CPG's trust requirements. The findings of this research indicated that mutuality, flexibility, and solidarity derived from relational norms are significant trust requirements in the CPG context. These results are aligned with those of previous studies about relational norms in the CPG context. For instance, Benítez-Ávila *et al.* (2018) argued that the CPG trust can be enhanced by mediating the effect of formal CPG designs and increasing project coalitions' capacity to coordinate tasks and reach high levels of cooperation. Similarly, mutual association through established normative practices and expectations in construction projects facilitates trust. The relational norms underpinning trust requirements yield positive

outcomes and foster a high degree of trust by curbing opportunistic behaviors in CPG environments (Xu *et al.*, 2021). However, previous studies have failed to define CPG trust requirements and the theories underpinning them. The study highlights the importance of utilizing a flexible bottom-up project governance approach for construction projects conceptualized as a common-pool resource and stigmergy instead of top-down governance approaches. Additionally, the examination of contingency theory as a governance theory revealed that the current CPG system diminishes trust in construction projects due to its inability to swiftly adapt to rapid changes in the construction project's internal and external environments. Likewise, network theory suggests that traditional CPG systems fall short in facilitating effective communication among project stakeholders in the intricate networks of construction projects, which erodes trust. In particular, project clients and main contractors (Li *et al.*, 2020), dealing with intricate interests involving multiple stakeholders, prioritize efficient and rapid decision-making in CPG. They should also emphasize network-based project management, scrutinizing network connection patterns, structures, node positions, and outcomes within the multifaceted networks of construction projects.

Nevertheless, previous research on blockchain-based CPG tended to focus on the control aspects of CPG, which emphasizes the relationship between BC and the tools of control-based CPG: contract management (Kim *et al.*, 2022), procurement management (Gupta and Jha, 2023), project assurance (Lu *et al.*, 2021a; Das *et al.*, 2022) and quality assurance (Lu *et al.*, 2022) – to limit opportunism in the construction network. In response to the limitations of previous studies, this study aimed to assess the relationship between CPG trust requirements and BC characteristics. This state-of-the-art review introduces new knowledge to CPG research by identifying that BC's six distinctive characteristics can increase CPG's three trust requirements. According to Ostrom (2019), there are many instances of common-pool resource situations where top-down governance has led to significant and consistent failures. In response to this project governance challenge, the result theoretically presents a basis for establishing a BC-aided relational CPG that can guide the reliable coordination and collective behaviors of construction project stakeholders through the bottom-up approach. The relational CPG through BC leads to structural relationships between network participants, enhancing trust through collaborative project networks under uncertain project environments (Liu *et al.*, 2022).

However, developing relational governance under complex construction environments demands significant time investment and resource-intensive social processes from project stakeholders (Xu *et al.*, 2022). In response to these challenges, this study provided the practical trust-based CPG model through BC (see Figure 3). The

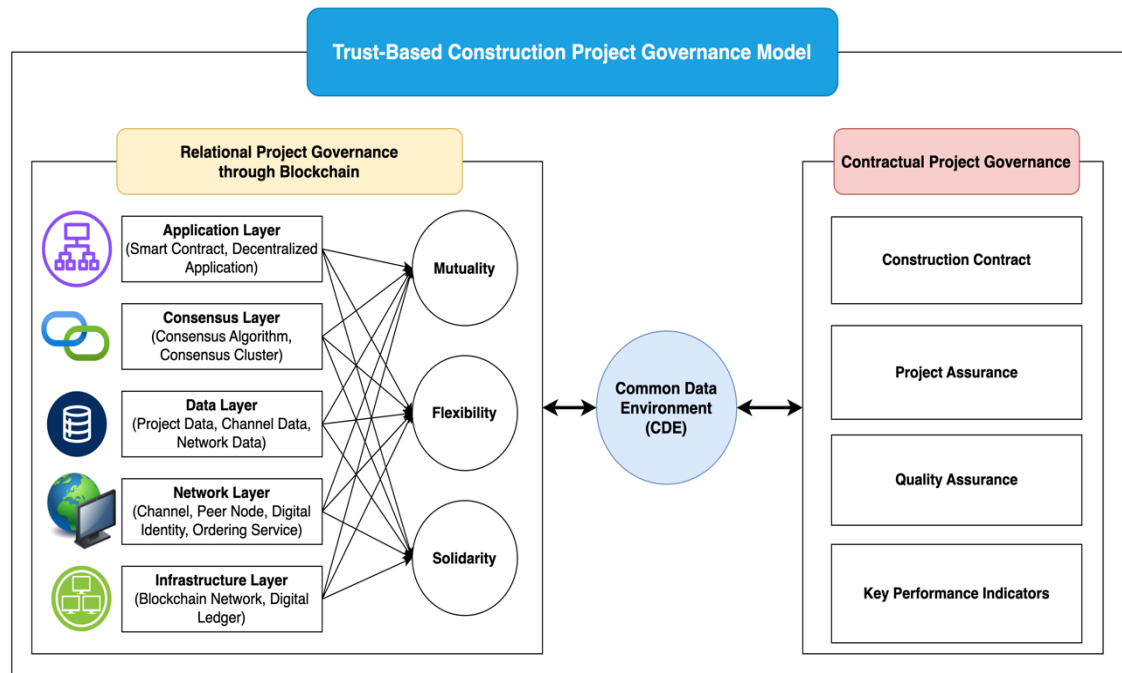


Figure 3: Trust-Based Construction Project Governance Model

findings indicate the possibility of developing a practical trust-based CPG model. Specifically, BC channels, nodes, orderers, and ledgers (Zhong *et al.*, 2020) can be configured, taking into account the unique context of each construction project. Additionally, a common data environment (CDE) can be used to connect existing CPG systems using construction contracts, project assurance, quality assurance and key performance indicators (KPIs). Trust among project stakeholders can be improved by securely storing, validating, and accessing project information using smart contracts. Ultimately, this trust-based CPG with BC can satisfy three trust requirements (mutuality, flexibility, and solidarity) of CPG. Therefore, this blockchain-enabled CPG, which is characterized by reliable decentralization, can efficiently govern and direct construction projects by enabling systematic self-organization and stigmaty environments. In particular, this system can provide novel insights allowing key project stakeholders (clients, main contractors, and consultants) to establish a trust CPG system while maintaining the existing governance system, including construction contracts and project assurance (Sergeeva, 2019).

Conclusions

This study, which adopted a state-of-the-art review, aimed to explore CPG's trust requirements and assess the relationship between CPG's trust requirements and BC's characteristics in construction projects distinguished by a common pool resource and stigmergy. The study revealed that CPG has three trust requirements: mutuality, flexibility, and solidarity. The distinctive six characteristics of BC; autonomy, decentralization, immutability, security, traceability and transparency can

improve these trust requirements. Consequently, the findings bridge the knowledge gap concerning the trust requirements of CPG and their association with BC. The result theoretically lays the groundwork for establishing a BC-supported relational CPG, guiding stakeholder behavior in construction projects. The findings also indicate the potential for a practical, trust-based CPG model by using BC. This research serves as a foundational step toward achieving fully automated, trust-based CPG systems.

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